

EUVL Embedded Phase Shift Mask Performance Evaluation

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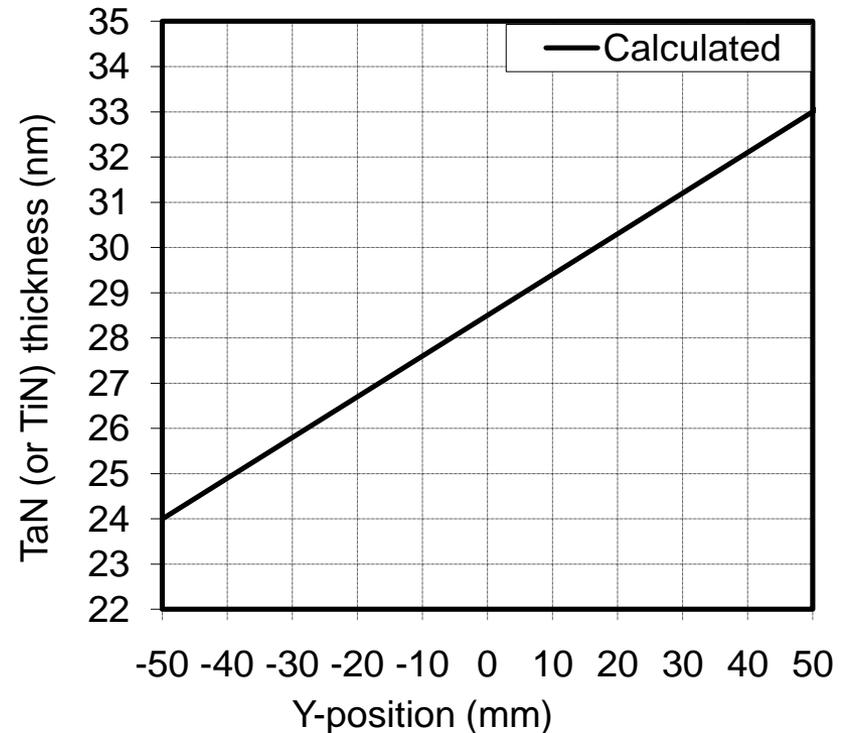
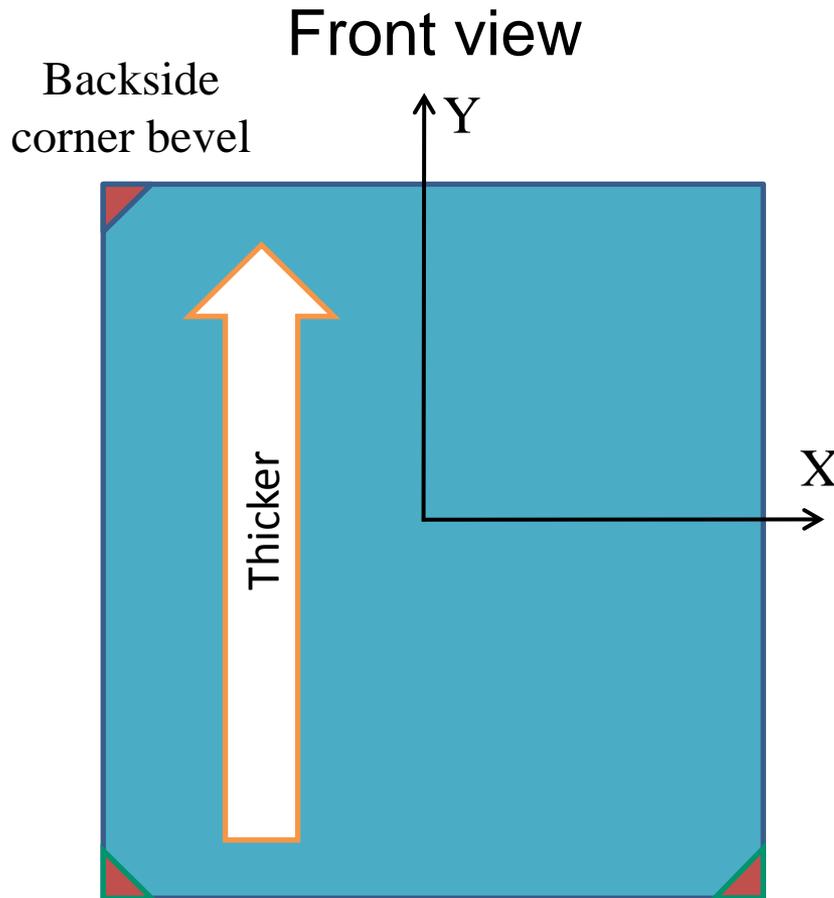
²Lawrance Berkeley National Lab

Outline

- EPSM and reference mask design
- Wafer data analysis
 - 40nm contact process window
 - 33nm dense line process window
 - 30nm dense line process window
 - Mask shadowing effect
 - EPSM phase error budget
- Conclusions

Gradient-thickness TiN/TaN EPSM Mask Blank Design

- enable EPSM phase error evaluation



- Equal thickness of TiN and TaN.
- Linear gradient in Y-direction.
- Uniform in X-direction.
- Measured R vs. Y-dimension matched well with the calculated values

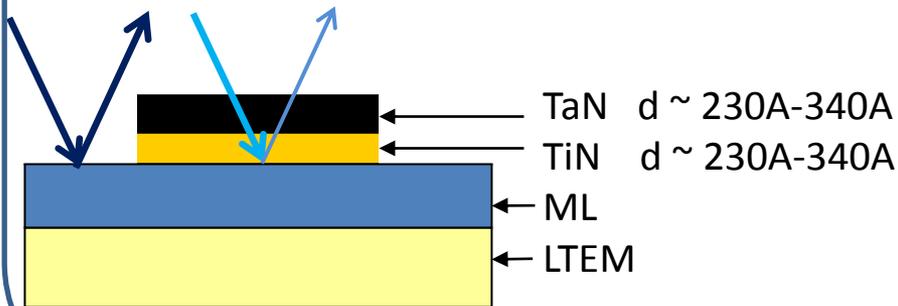
EUV EPSM and Reference Mask Design

One EUV EPSM and one standard EUVL mask (reference mask) were fabricated
Wafer printing comparison between the two masks were accessed

EUV EPSM design

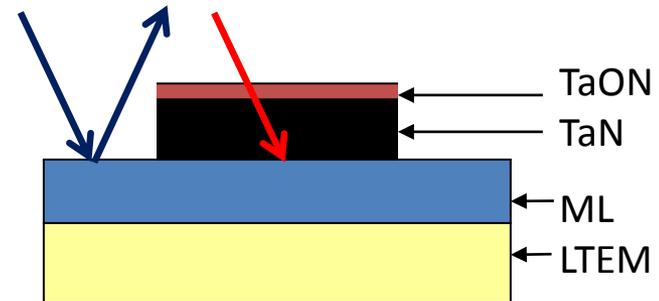
	TaN	TiN
n (13.5nm)	0.9420	0.9401
k (13.5nm)	0.0337	0.0195

$$d(\text{TaN}) = d(\text{TiN})$$

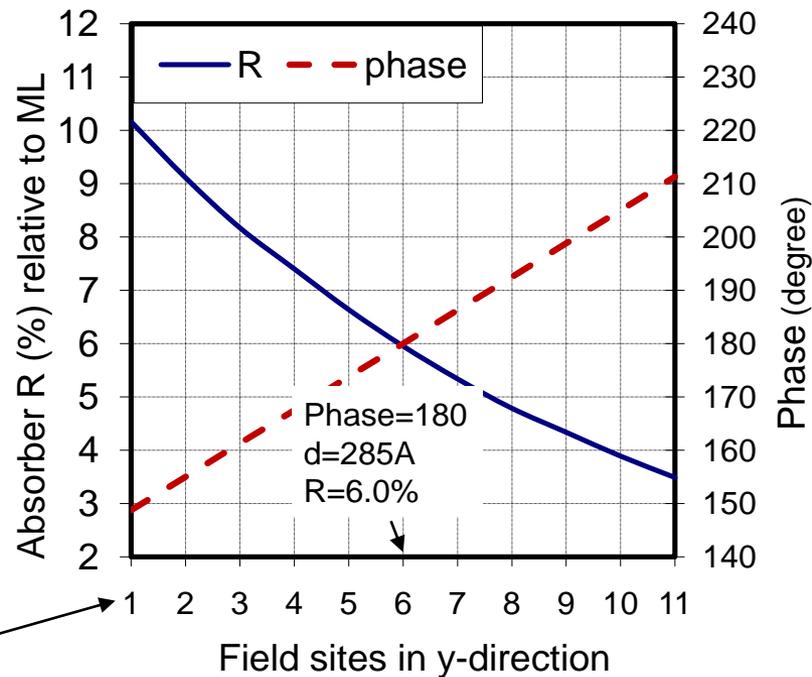
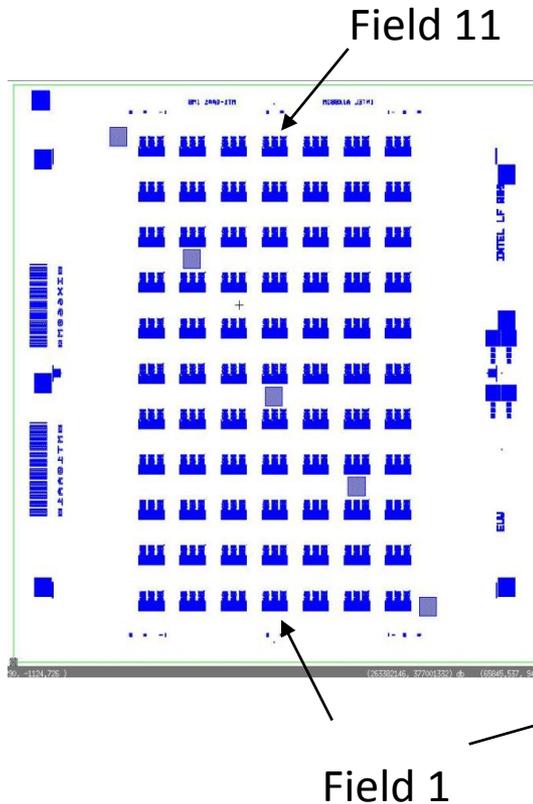


Standard EUVL mask design (Reference mask)

$$d(\text{TaN}) + d(\text{TaON}) = 85\text{nm}$$



EPSM Blank Reflectivity/Phase at Each Field Location



Phase/R vs. Locations

Location	Phase	R
11	214	3.5
10	207	3.9
9	200	4.3
8	194	4.8
7	187	5.3
6	180	6.0
5	173	6.6
4	166	7.4
3	160	8.2
2	153	9.1
1	146	10.2

- The center field (location 6) has the correct 180 phase with reflectivity ~6%.

Wafer Exposure Conditions:

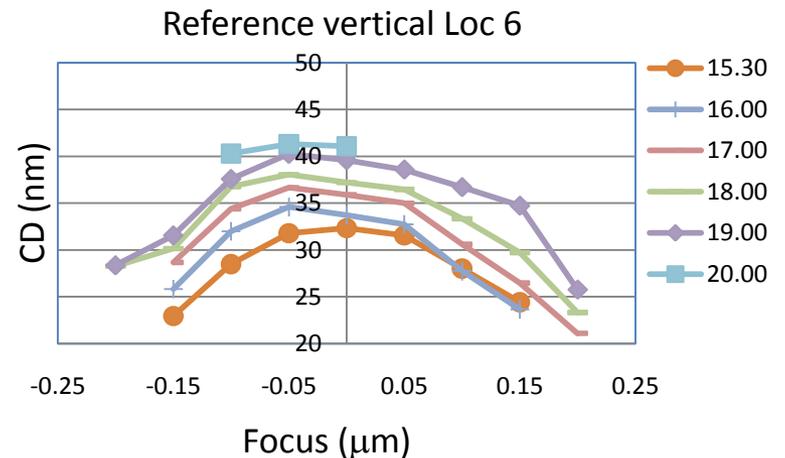
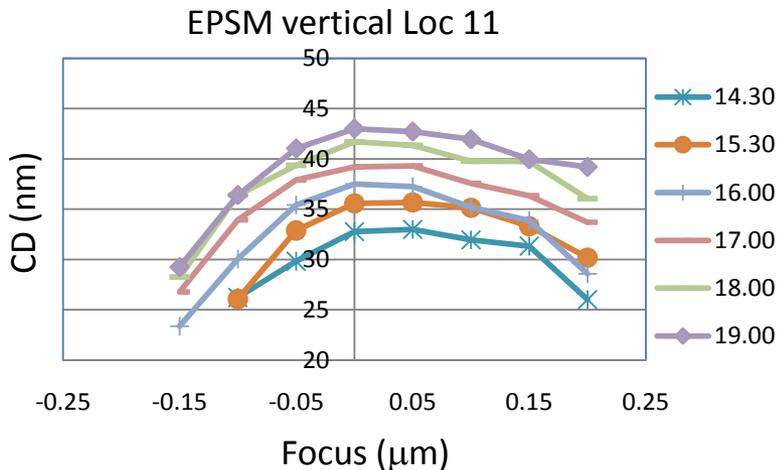
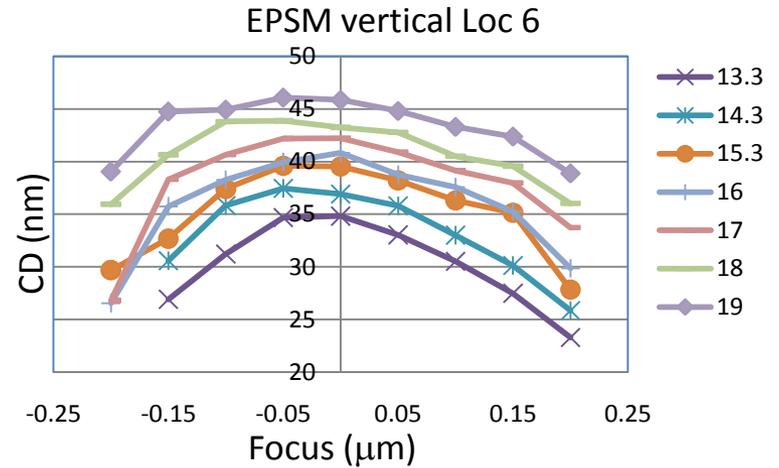
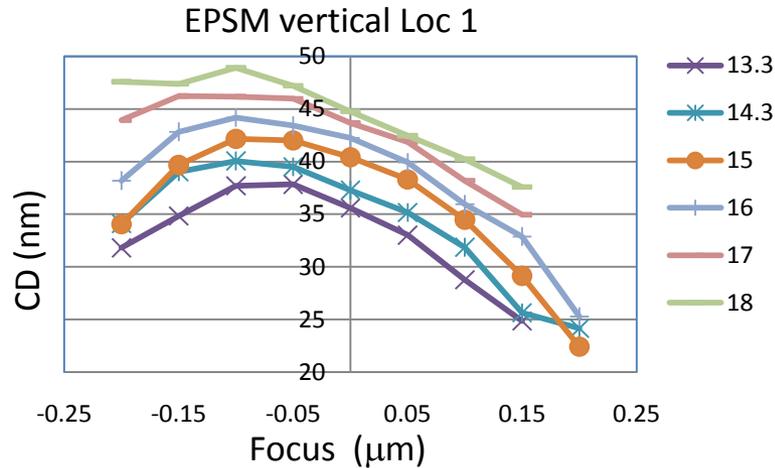
ADT: NA=0.25, $\sigma=0.5$

Resist: SEVR59



Contact Results: EPSM Locs 1, 6, 11, Ref Loc 6

-40nm dense contacts CD vs. Focus for different doses



- EPSM best focus shifts from left to right when the field location changes from 1 (phase 146 degrees) to 6 (phase 180 degrees) to 11 (phase 214 degrees) due to designed phase error.
- Larger Bossung cure tilt at location 1 as compared to that of location 6.



40nm Dense Contacts Process Window Analysis

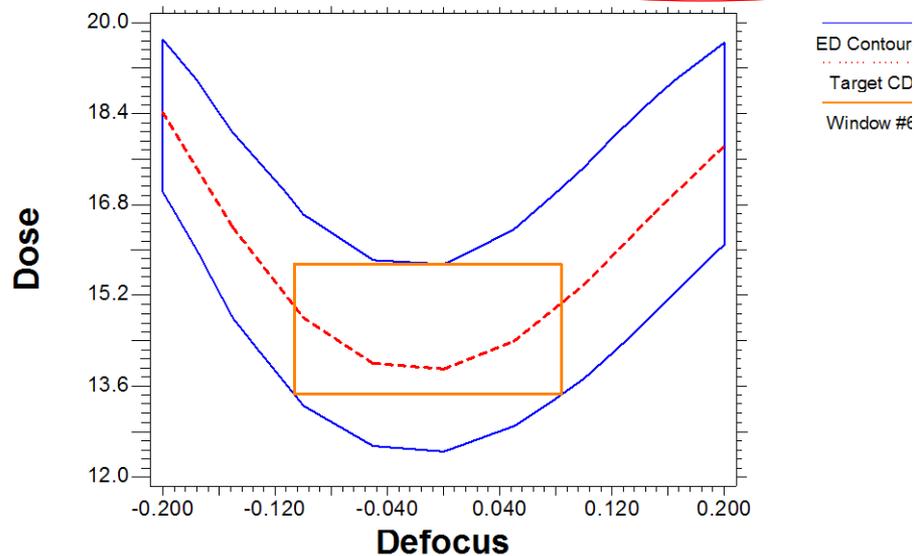
Data analysis target CD=36nm +/-4nm
For maximum process window

	DOF (nm)	% Exp Latitude
EPSM	190	7.87
Reference	180	6.72

CD Min = 32, Max = 40, Target = 36

Dataset : loc6-epsm+, ED Analysis

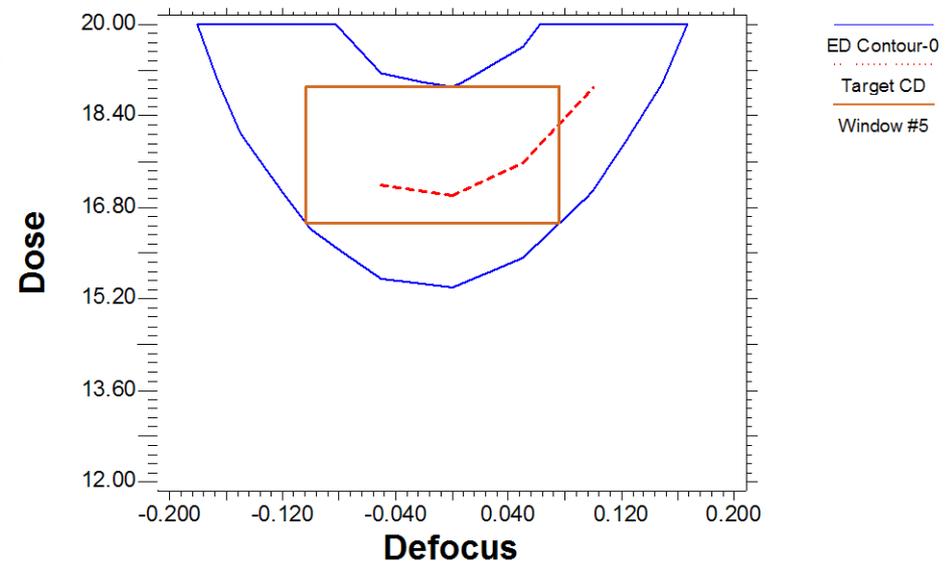
Largest Sol. Area -> Center_Focus = -0.011, Center_Dose = 14.598



CD Min = 32, Max = 40, Target = 36

Dataset : loc6-ref+, ED Analysis

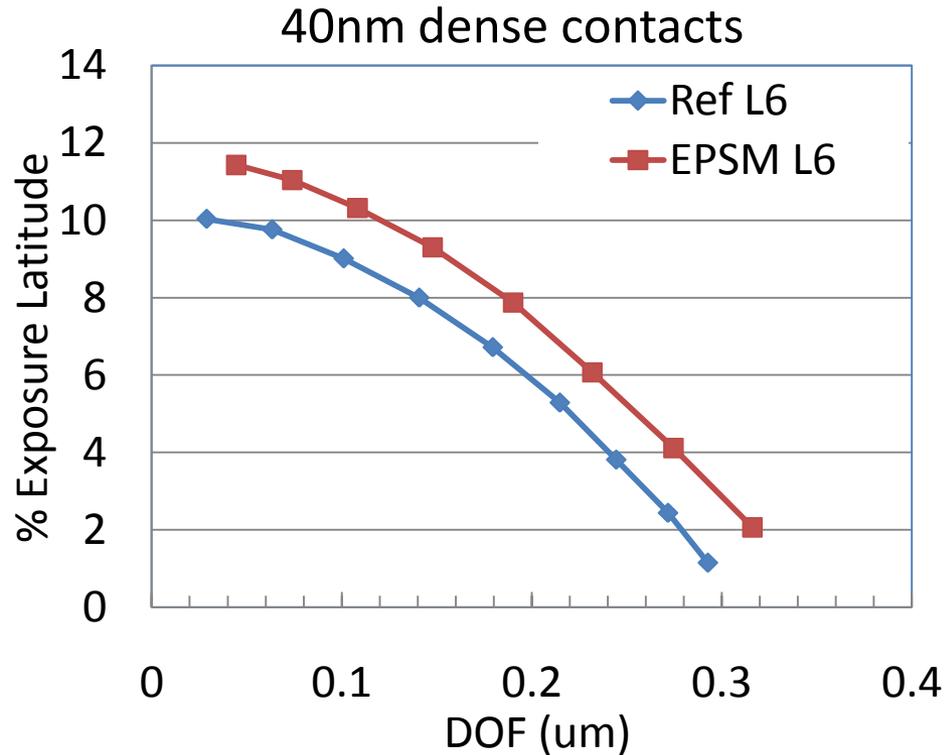
Largest Sol. Area -> Center_Focus = -0.014, Center_Dose = 17.716



- EPSM showed 24% larger F-E process window than that of the referent mask.
- Dose-to-target for EPSM is about 18% lower than that for the reference mask.



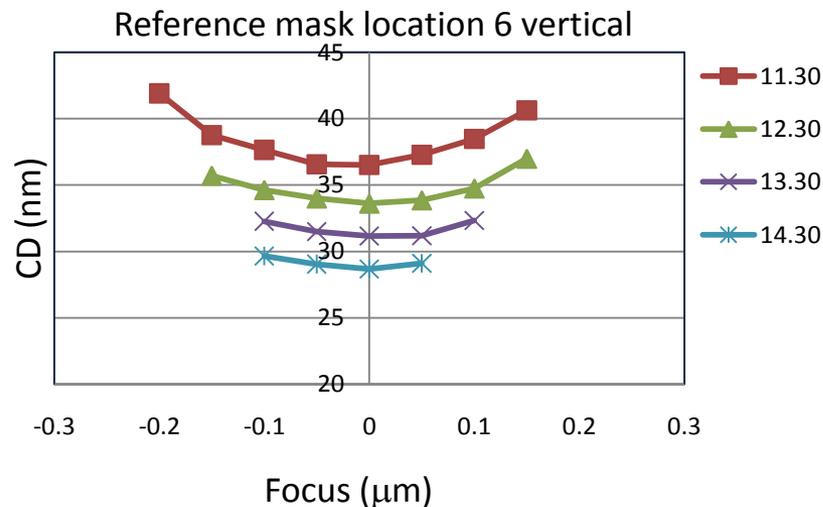
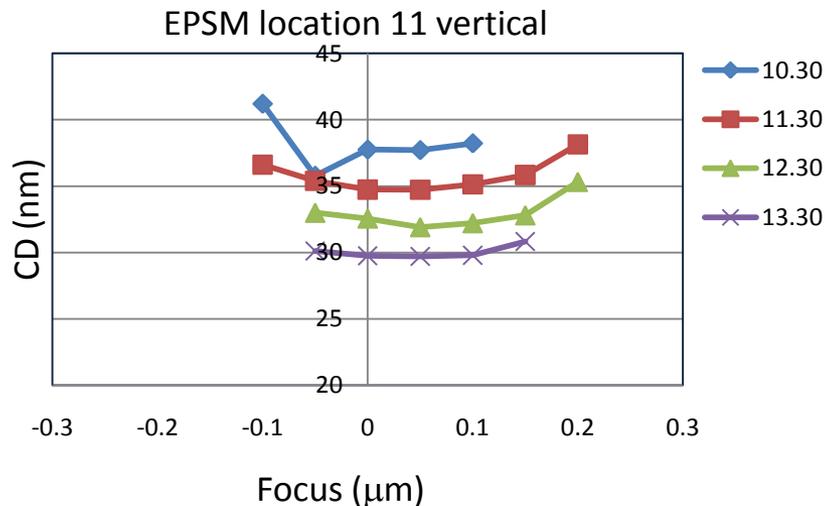
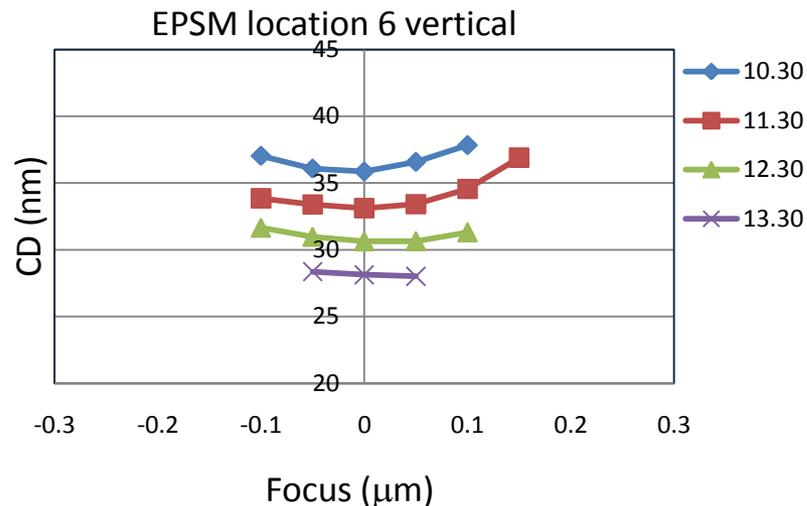
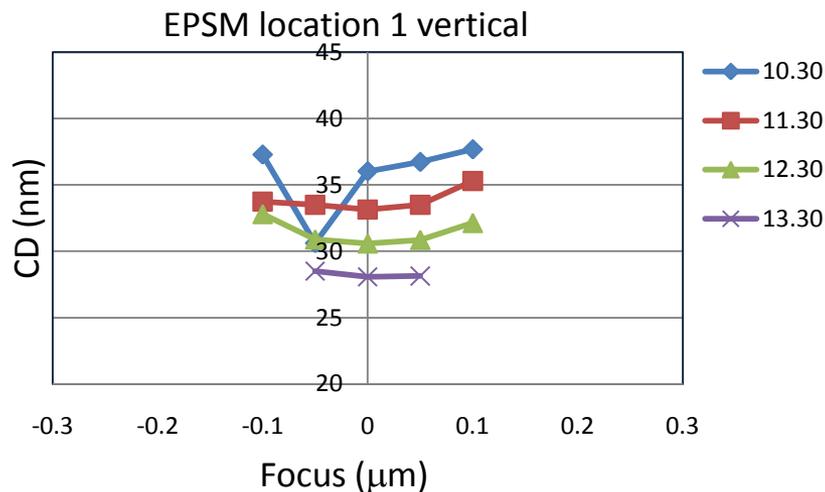
40nm Dense Contacts Process Window Analysis (cont'd)



- For any given % exposure latitude, the DOF is consistently larger for EPSM than that of reference mask.



33nm L/S Results : EPSM Loc 1,6,11, & Ref Loc 6



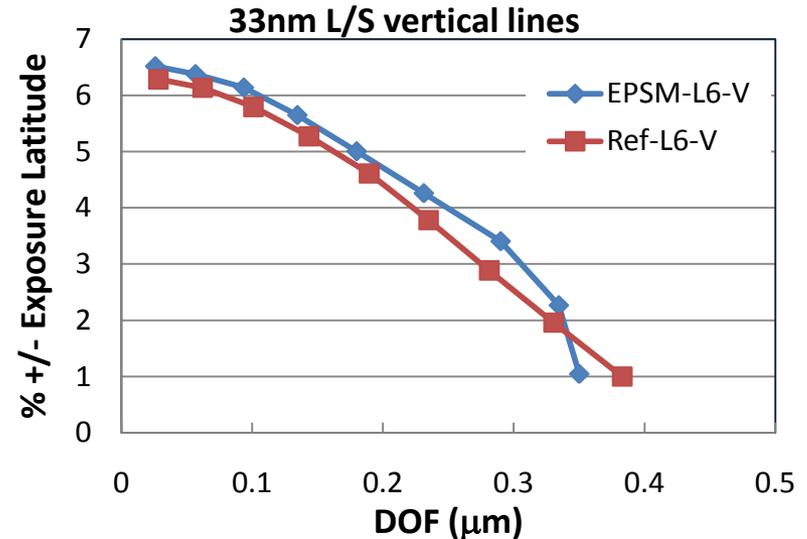
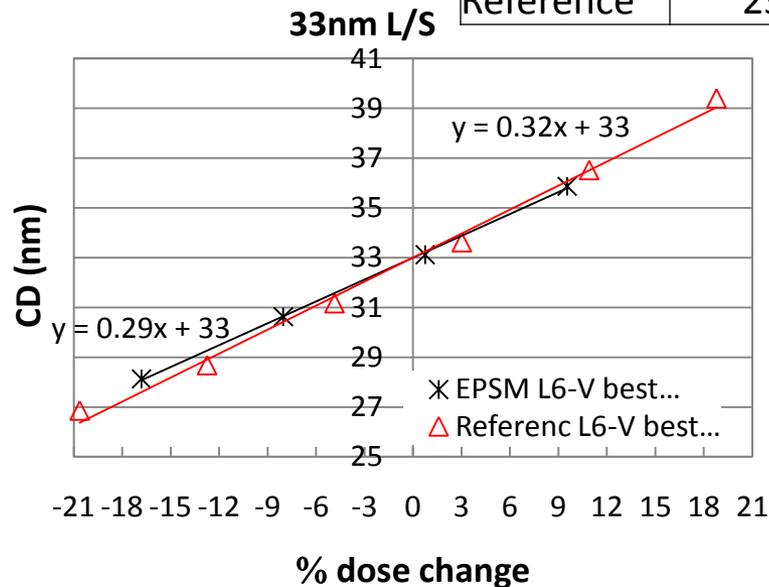
- EPSM best focus shifts from left to right when the field locations change from 1 \Rightarrow 6 \Rightarrow 11 due to the designed phase error.



33nm L/S Vertical Lines Process Window Analysis (cont'd)

Data analysis target CD=33nm +/-2nm
For maximum process window

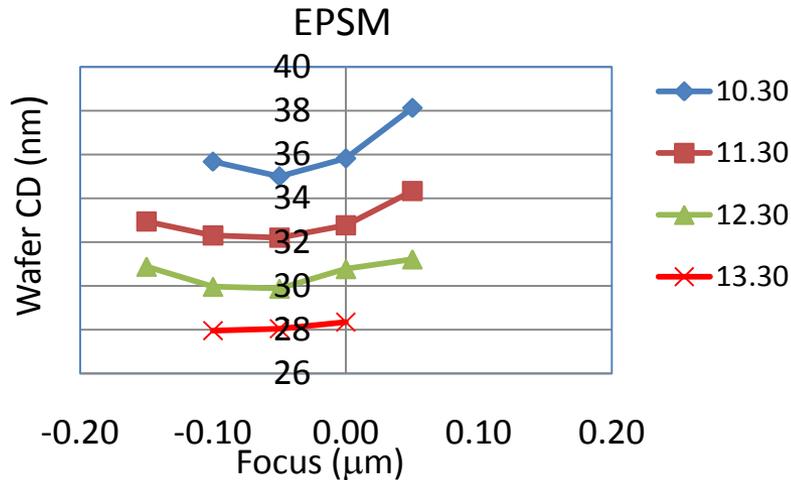
	DOF (nm)	Exp Latitude(%)
EPSM	231	4.26
Reference	235	3.78



- At best focus, $\Delta\text{CD}/\Delta\text{dose}$ is smaller for EPSM than that of reference mask.
- EPSM showed 11% larger F-E latitude than that of reference mask (not as much gain as that for the contacts).
- Dose-to-target is about 9% lower for EPSM as compared to that of referent mask (11.74 vs. 12.89)

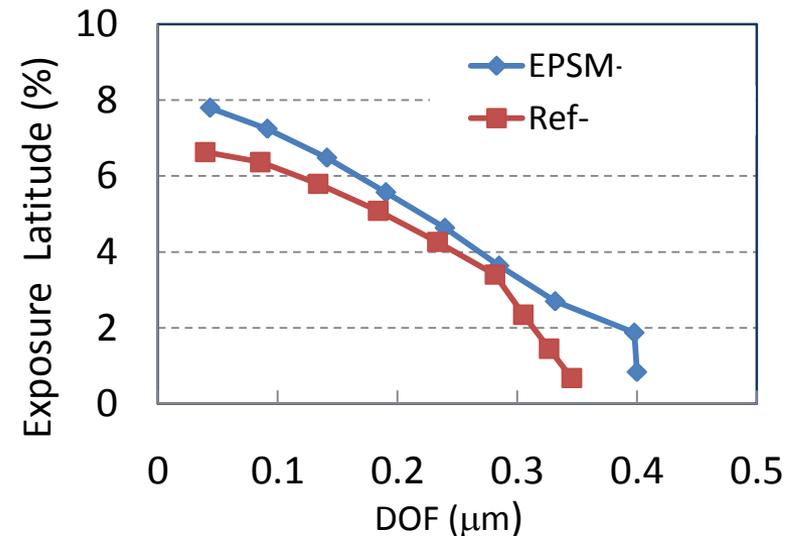
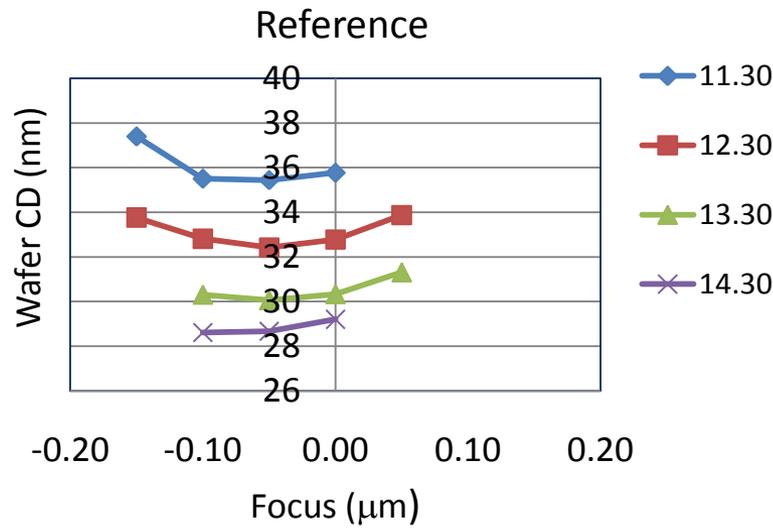


30nm L/S Horizontal Line Process Window Analysis



Data analysis target CD=30nm +/-2nm
For maximum process window

	DOF (nm)	Exp Latitude(%)
EPSM	240	4.63
Reference	233	4.27



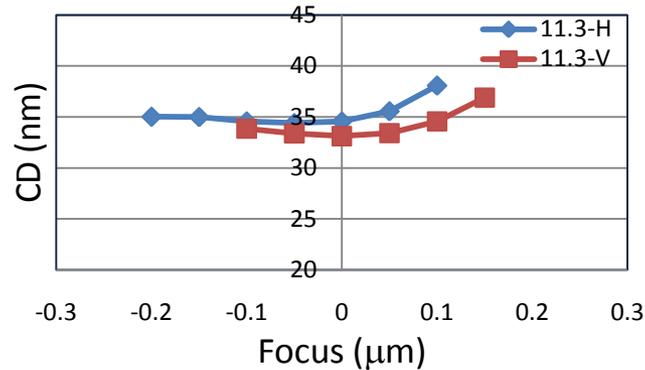
➤ EPSM showed 12% larger F-E latitude than that of reference mask.



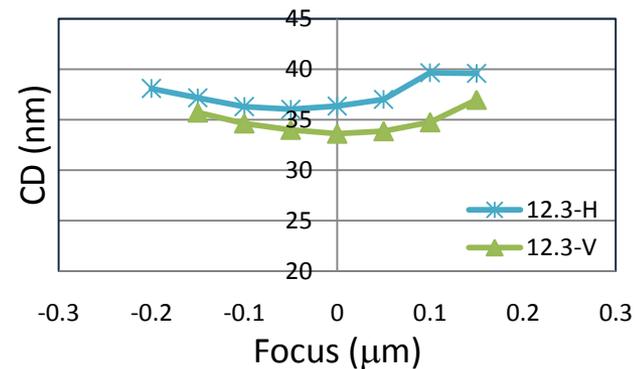
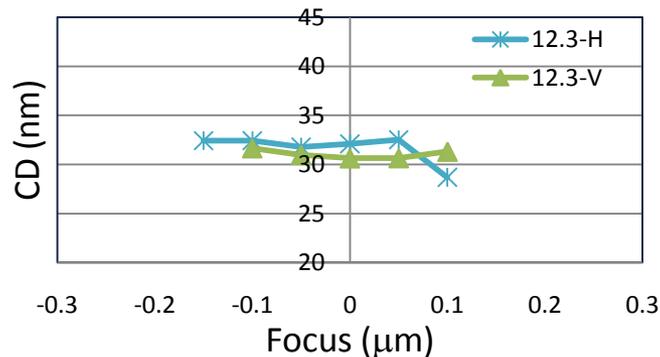
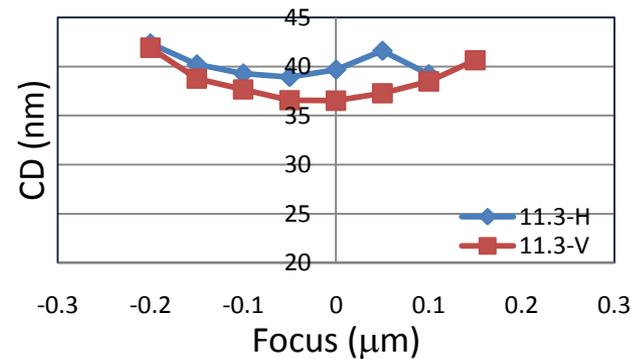
Shadowing Effect Comparison

33nm dense vertical lines vs. horizontal lines

EPSM Location 6 (absorber height=56nm)



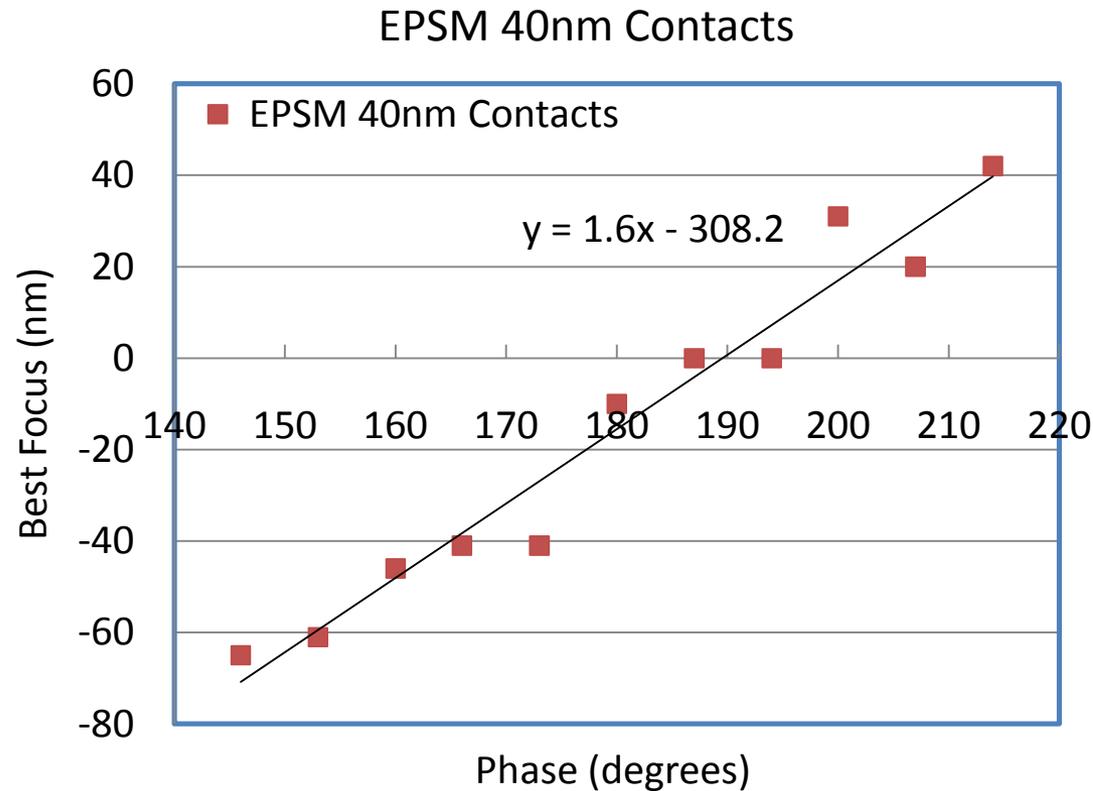
Ref location 6 (absorber height=85nm)



- There is ~ 50nm H-V focus difference due to astigmatism.
- The average (over different dose) H-V CD difference after H/V focus correction:
 - EP SM: 1.2nm (geometric prediction: 2.94nm)
 - Reference Mask: 2.5nm (geometric prediction: 4.47nm)
- EP SM shadowing effect is less than half of that of reference mask while its absorber thickness is more than half of that of the reference mask.



EPSM Phase Error Analysis



- If $\pm 3\text{nm}$ focus variation is allowed:
 - allowed phase variation is ± 2 degrees,
 - allowed total film stack thickness variation is $\pm 0.6\text{nm}$

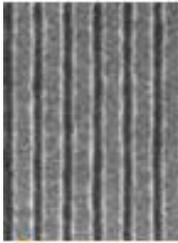
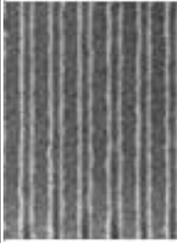
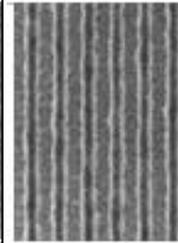
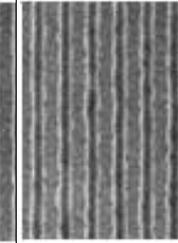
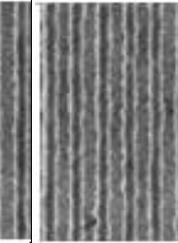
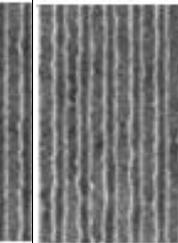
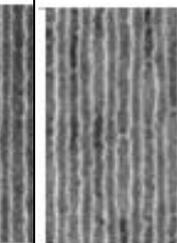
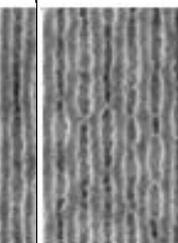
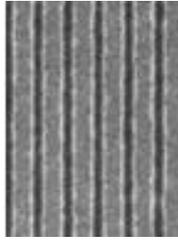
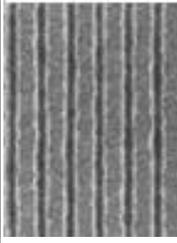
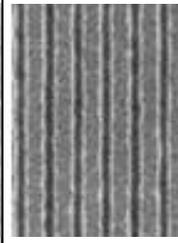
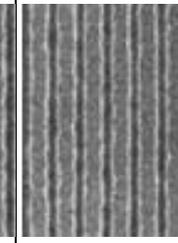
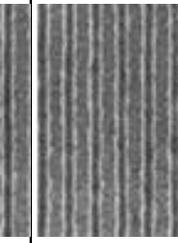
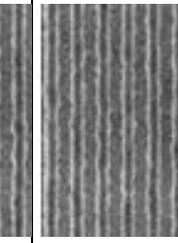
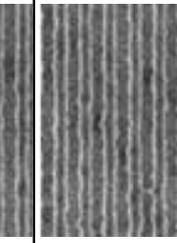
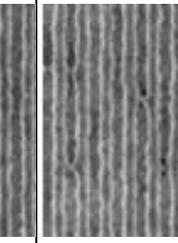
Dense (L/S) Vertical Line SEM Image Comparison

Designed CD	33nm	32nm	31nm	30nm	29nm	28nm	27nm	26nm	25nm
Measured wf CD	32.81nm	31.40nm	31.50nm	30.80nm	29.95nm	29.90nm	30.04nm		
Reference Vertical F=0 (best focus) Dose=12									
Measured wf CD	31.20nm	29.93nm	29.77nm	28.94nm	28.14nm	27.50nm	28.20nm	28.93nm	
EPMS Vertical F=0 (best focus) Dose=11									
Measured wf CD	32.77nm	31.7nm	31.82nm	30.64nm	30.81nm	29.96nm	30.38nm		
Reference Vertical F=-50nm Dose=12									
Mesured wf CD	33.78nm	32.02nm	31.99nm	30.95nm	30.09nm	29.45nm	30.22nm		
EPMS Vertical F=-50nm Dose=11									

➤ EPMS showed slightly better resolution than that of conventional EUVL mask

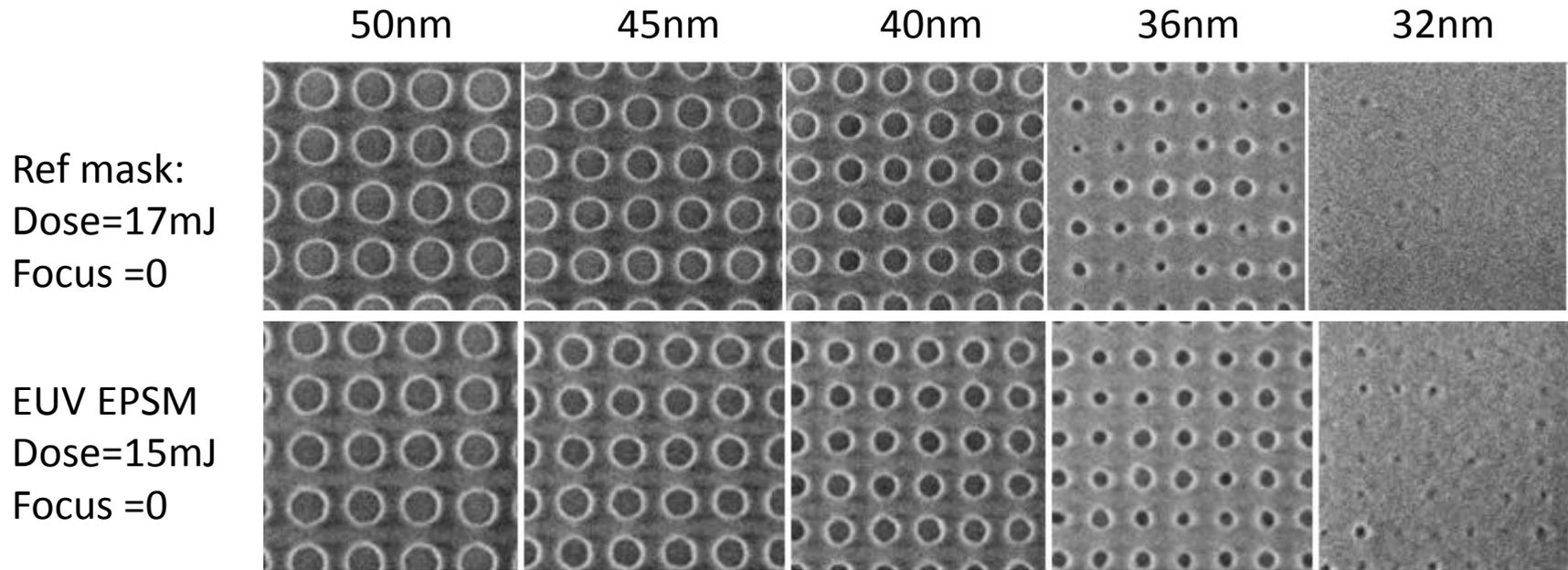


Dense (L/S) Horizontal Line SEM Image Comparison

Designed CD	33nm	32nm	31nm	30nm	29nm	28nm	27nm	26nm
Measured CD	35.08nm	31.05nm	32.56nm	32.08nm	32.94nm	31.78nm	32.66nm	
Reference Horizontal F=-50nm (best focus) Dose=12								
Measured CD	34.04nm	31.74nm	31.96nm	30.58nm	30.20nm	30.39nm	30.01nm	29.97nm
EPSM Horizontal F=-50nm (best focus) Dose=11								

➤ Again EPSM showed slightly better resolution than that of conventional .EUVL mask

Dense Contact Resolution Comparison



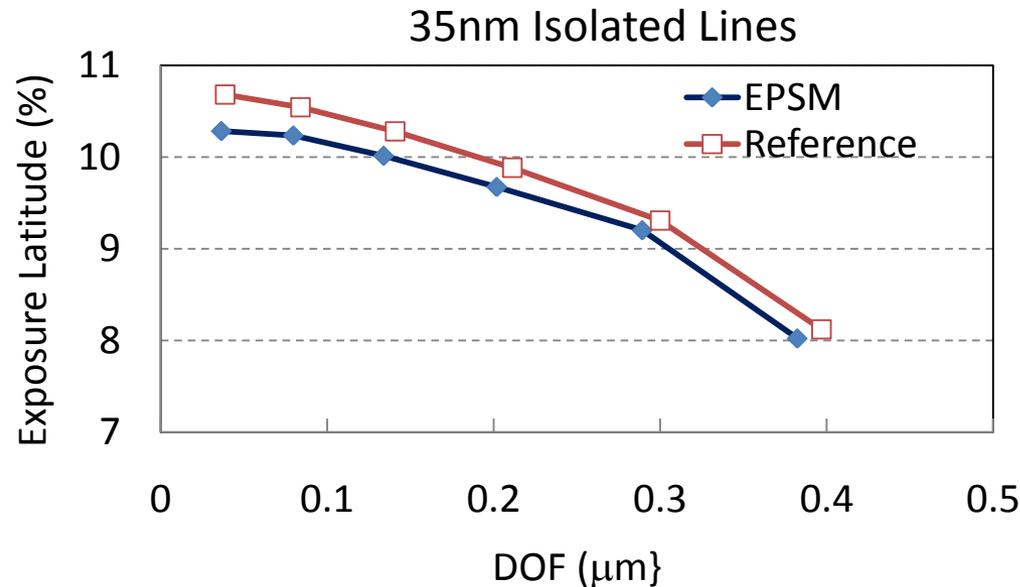
Isolated Vertical Line Process Window Analysis

35nm isolated lines

Location 6: data analysis target CD=35nm +/-2nm

For maximum process window

	DOF (nm)	Exp Latitude(%)
EPSM	382	8.02
Reference	397	8.12



- Reference mask showed 5% larger F-E latitude than that of EPSM.
- Advantage of EPSM is for the dense features.



Conclusions

- For 6% EPSM as compared to conventional EUVL mask:
 - ✓ 24% process window improvement obtained for dense contacts.
 - ✓ Slight resolution & process widow improvement obtained for dense lines.
 - ✓ 2x reduction in shadowing effect obtained.
 - ✓ 18% and 9% dose-to-target reduction obtained for dense contacts and for dense lines, respectively.
 - 5% process window reduction or isolated lines
- Absorber uniformity requirement ($<+/-0.6\text{nm}$) for EUV EPSM is within the current process capability.



Acknowledgement

- Farhad Salmassi from LBNL for thin film deposition support.
- Ken Buckmann and Vijayakumar Ramachandrarao from Intel for mask fabrication support.
- IMEC for EUV wafer exposure support.

